Estimation of Temporally Evolving Typhoon Winds and Waves from Synthetic Aperture Radar

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LONG-TERM GOALS

The long term goal is to develop a methodology for using synthetic aperture radar (SAR) data to improve characterization of the winds and waves generated by typhoons in the western Pacific Ocean.

OBJECTIVE

The objective is to develop a variational assimilation algorithm based on the SWAN model to estimate the near-surface typhoon wind field from SAR data.

APPROACH

Third-generation wave spectrum models such as SWAN can be used to predict wind-generated waves. Combining SWAN and a model relating the SAR-image spectrum to the computed wave spectrum, one can predict the SAR-image spectrum which results from a known wind field. Using variational data assimilation, this relationship can be inverted to estimate the wind field from SAR data. The focus of this effort is to extend an existing SAR assimilation algorithm to enable the estimation of surface wind fields from SAR data.

An assimilation algorithm has been developed to estimate the ocean-wave field for a near-shore region for stationary conditions using SAR data (Walker 2006). The algorithm is variational in nature and is based on the SWAN 40.51 ocean-wave-spectrum model (Ris *et al.* 1999, Booij *et al.* 1999) coupled to the nonlinear SAR-spectrum model of Hasselmann and Hasselmann (1991). For this case, the algorithm is used to estimate the boundary conditions for SWAN that result in a wave-spectrum prediction which best fits the SAR data.

To extend this algorithm to estimation of typhoon wind and wave fields, the algorithm must be modified for application to non-stationary conditions, and the expressions for the gradient of the cost function with respect to the wind field must be developed and incorporated in the algorithm. The completed algorithm will be verified by applying the algorithm to simulation data, where all the conditions are known in detail.

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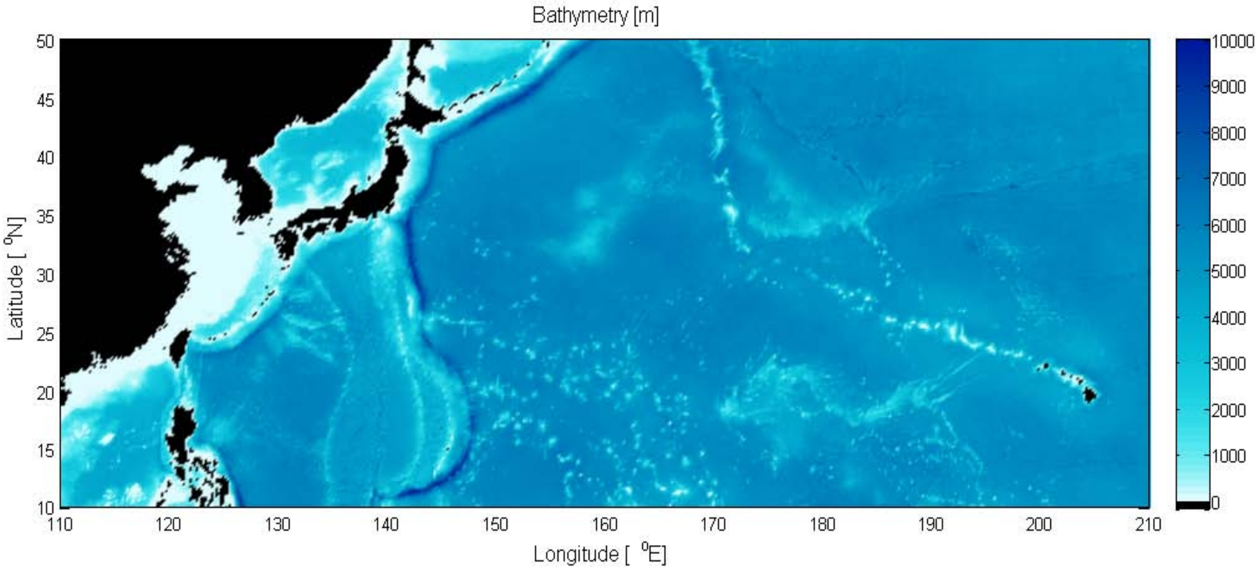

Figure 1 Bathymetry for region of SWAN model computations.

Initial algorithm validation will be carried out by applying the algorithm to existing SAR typhoon/hurricane data sets, and comparing the resulting wind and wave field estimates to in-situ and other observational data. The algorithm will be applied to data collected as part of the ONR Departmental Research Initiative on the Influence of Typhoons on the Western Pacific (ITOP DRI). Algorithm results will be validated using other observational data collected under DRI auspices.

WORK COMPLETED

This program started late in the fiscal year and activities to-date have focused on establishing the mathematical framework for the assimilation algorithm and developing the appropriate test cases around which algorithm development will revolve.

RESULTS

To develop test cases for the algorithm development effort, the SWAN model was configured for a region from 110°E to 150°W and 10° to 50°N encompassing the western Pacific from Hawaii to the Chinese mainland, including Japan, Korea, Taiwan and the northern Philippines (see Figure 1). The initial step was to determine the appropriate specification of boundary conditions, initial conditions and forcing to produce realistic results from the SWAN model for this region.

The SWAN model grid has a spatial resolution of 0.2˚, and the wave spectra are discretized with 48 directions (7.5˚ resolution) and 25 frequencies (0.41 – 0.041 Hz). The bathymetry was obtained from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_08, a global 30 arc-sec grid. Input 10 m wind fields are from the Navy Operational Global Atmospheric Prediction System (NOGAPS) model provided by the Fleet Numerical Meteorology and Oceanography Center (FNMOC). These analysis wind fields are on a 0.5° grid and generated every 12 hours.

Figure 2 shows the track for Typhoon 09W (Morakot) which made landfall on Taiwan on 08 August 2009. This case was computed using SWAN starting from 01 August and continuing through 09 August using the NOGAPS 10 m winds and homogeneous spatial boundary conditions. The SWAN results are shown in Figure 3. Also shown in Figure 3 are the NOGAPS wind fields and results from global operational Wavewatch 3 (WW3) forecasts produced by FNMOC on a 0.5° spatial grid, with 24 spectral direction bins (15˚ resolution) and 25 frequencies (0.42 – 0.04 Hz), roughly half the spatial and directional resolution of the SWAN results.

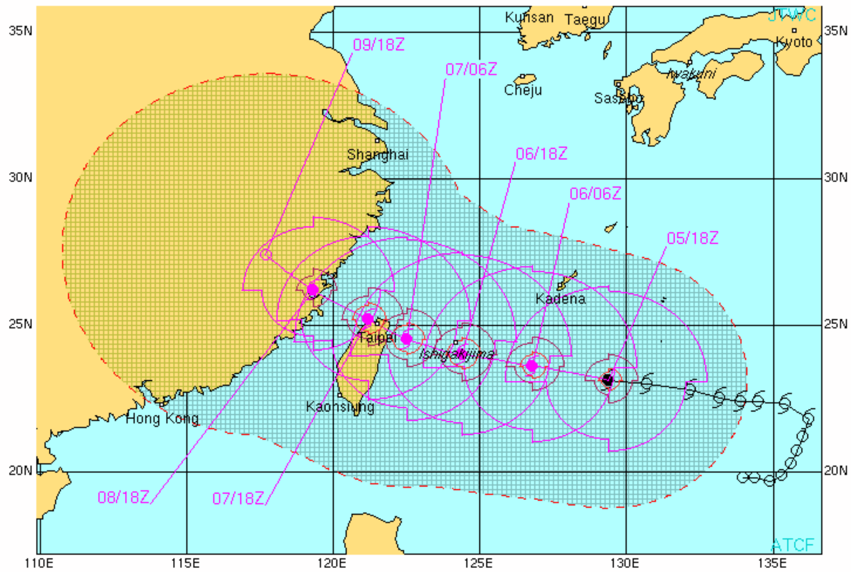

Figure 2 Typhoon 09W (Morakot) on 05 August 2009 showing the predicted track.

In Figure 3, the difference in resolution between SWAN and WW3 are apparent; in the global-scale computations, many of the land features are poorly resolved. Comparison of the wave simulations shows that in the region of the typhoon, finer details of the wave field are distinguishable in the SWAN results but, overall, are comparable to the lower resolution WW3 results. After landfall (09 August), the SWAN near-shore model predicts substantially larger wave heights and more small-scale variation than the global-scale simulations. Since the SWAN computations were done using only the NOGAPS winds as input, these results show that for the region examined, multiple-day computations with SWAN do not show significant influence from the open boundaries. This tentative result indicates that nesting of the SWAN computations for this region into the global WW3 computations is not necessary, simplifying the data assimilation process.

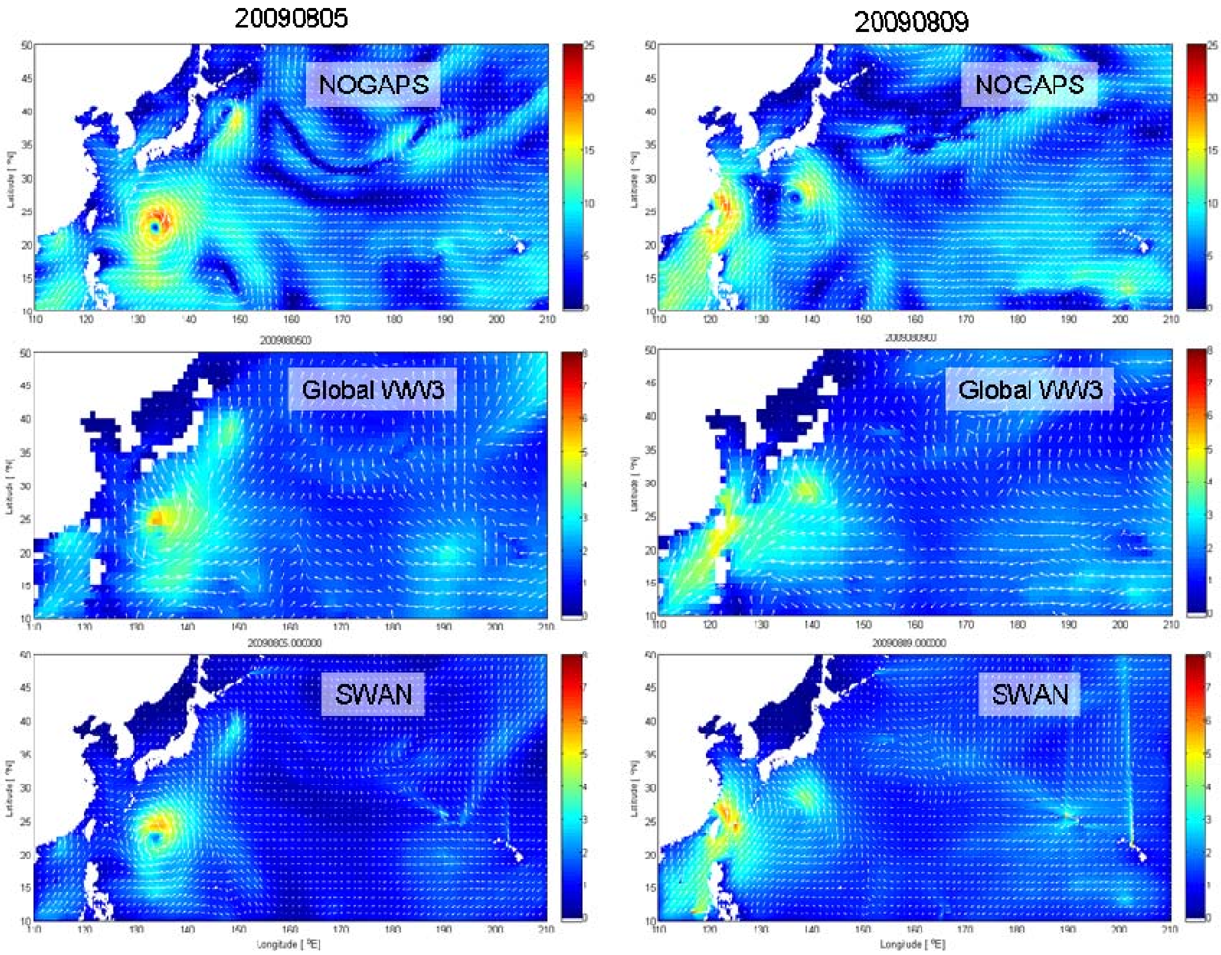

Figure 3 Comparison of SWAN computations started from 01 August 2009 using NOGAPS winds to WW3 operational forecasts for 05 and 09 August 2009. Top: NOGAPS 10 m analysis wind fields. Middle: FNMOC global WW3 significant wave heights and wave directions. Bottom: SWAN significant wave height and wave direction.

Going forward, additional simulations of the sort shown in Figure 3 are being carried out to sort out numerical aspects of computing these extreme wave cases over this large domain at high resolution (e.g. some evidence of spurious wave heights around Hawaii and Midway Island are present in the eastern portion of the SWAN results in Figure 3, most likely due to interpolation issues with the bathymetry field). The assimilation algorithm is also being extended to this problem, at present using simulated data.

IMPACT/APPLICATIONS

If successful, the algorithm developed here will enable improved operational prediction of tropical cyclone evolution.

RELATED PROJECTS

This program is part of the ITOP Departmental Research Initiative

REFERENCES

Booij, N., Ris, R.C. & Holthuijsen, L.H. 1999 A third-generation wave model for coastal regions: 1. Model description and validation. *J. Geophys. Res.* **104**, 7649.

Hasselmann, K. & Hasselmann, S. 1991 On the nonlinear mapping of an ocean-wave spectrum into a synthetic aperture radar image spectrum and its inversion. *J. Geophys. Res.* **96**, 10 713–10 729.

Ris, R.C., L.H. Holthuijsen and N. Booij 1999 A third-generation wave model for coastal regions: 2. Verification. *J. Geophys. Res.* **104**, 7667.

Walker, David T. 2006 *Assimilation of SAR imagery in a nearshore spectral wave model.* Report No. 200306-F. General Dynamics Advanced Information Systems, Ypsilanti, MI.